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ORIGIN AND DISTRIBUTION OF CLAY MINERALS IN THE COASTAL AREA OF WEST CENTRAL SENEGAL, WEST AFRICA

Aïdara C. A. Lamine FALL

Department of Geography, University Assane Seck of Ziguinchor,
BP 523 Ziguinchor, Senegal

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* Correspondance, e-mail : *chérif.fall@univ-zig.sn*

ABSTRACT

Our study investigates the origin and distribution of clay minerals in the coastal area of West central Senegal, West Africa, in order to demonstrate their impact on local pedogenesis. A sequence of six soil profiles located at three landscape positions: floodplain (2), low terrace (2), middle terrace (2); was described in the field, and 29 soil samples were collected for laboratory analyses. Clay mineralogy was determined by X-ray diffraction of oriented clay specimens. The different treatments of clay samples included K and Mg saturation, heating to 110°C, 220°C, 400°C and 600°C of the K- and glycerol salvation of the Mg-saturated samples. The amounts of the different clay minerals were estimated on a semi-quantitative basis using the computer package DIFFRAC AT V3.3 Siemens 1993. The results show that kaolinite, smectite, illite, and illite/smectite are the main clay minerals present in studied soils. Kaolinite dominates in abundance and cristallinity. It is present in all soils, but remains more prominent in the low terrace (84 % of the clay mineral assemblage, vs. 72 % in the floodplain and 62 % in the middle terrace). Smectite is also present in all soils; it shows highest values in the middle terrace (37 %, vs. 26 % in the floodplain, and 15 % in the low terrace). Clay minerals are partly authigenic, partly detrital. Authigenic clay minerals are influenced by acid and saline conditions. The distribution of detrital clay minerals is governed by the landscape position, which determines the importance of eolian inputs.

Keywords : *clay minerals, origin and distribution, coastal area, Senegal, West Africa.*

RÉSUMÉ

Origine et distribution des minéraux argileux sur la zone côtière du centre-ouest du Sénégal, Afrique de l'Ouest

Notre étude investit l'origine et la distribution des minéraux argileux de la zone côtière du centre-ouest du Sénégal, en Afrique de l'Ouest, afin de démontrer leur impact sur la pédogenèse locale. Une toposéquence composée de six profils pédologiques situés à trois positions topographiques différentes: plaine alluviale (2), terrasse basse (2) et terrasse moyenne (2); a été décrite in situ et 29 échantillons de sol ont été prélevés pour des analyses en laboratoire. Les minéraux argileux ont été déterminés par diffractométrie aux rayons X. Les différents traitements des échantillons d'argile comprenaient la saturation en K et Mg, le chauffage à 110 ° C, 220 ° C, 400 ° C et 600 ° C pour les échantillons saturés en K et traitement au glycérol des échantillons saturés en Mg. Les minéraux argileux ont, par la suite, été estimées sur une base semi-quantitative à l'aide du logiciel DIFFRAC AT V3.3 Siemens 1993. Les résultats montrent que la kaolinite, la smectite, l'illite et l'illite / smectite sont les principaux minéraux argileux présents dans les sols étudiés. La kaolinite domine en abondance et cristallinité. Elle est présente dans tous les sols, mais reste plus importante sur la terrasse basse (84 % des minéraux argileux, contre 72 % sur la plaine alluviale et 62 % sur la terrasse moyenne). La smectite est également présente dans tous les sols; elle montre les valeurs les plus élevées sur la terrasse moyenne (37 %, contre 26 % sur la plaine alluviale et 15 % sur la terrasse basse). On peut retenir de cette étude que les minéraux argileux de la zone côtière du centre-ouest du Sénégal sont partiellement authigènes et partiellement détritiques. Les minéraux argileux authentiques sont influencés par les conditions acides et salines du milieu, alors que la distribution des minéraux argileux détritiques dépend largement de la position topographique du site, qui détermine l'importance des apports éoliens.

Mots-clés : *minéraux argileux, origine et distribution, zone côtière, Sénégal, Afrique de l'Ouest.*

I - INTRODUCTION

Clay minerals are ubiquitous in earth-surface conditions (in soils, weathering profiles, etc.). In soils, they are frequently used as indicators of pedogenesis because the mineralogy of the clay fraction is related to the pedogenic processes that have occurred in the soil [1]. It has long been recognized that clay minerals strongly influence the major physical and chemical properties of soils and, consequently, questions concerning the origin, distribution and formation of these minerals have assumed prominence in soil research [2]. The clay minerals in soils at present are derived from various sources, which may be natural or anthropogenic. They are inherited from the parent rock, atmospheric deposits, fertilizers and/or precipitated from the soil solution. They reflect successive stages of mineralogical evolution depending on the various environmental conditions that have prevailed during soil formation [3, 4]. So, these clay minerals could record the overall environmental conditions [5]. Clay minerals have been widely used in studies of sedimentary dynamics studies. Their physical and chemical properties make them good indicators of sediment sources, and their distribution patterns in the sedimentary basins can be indicative of the main transport processes and pathways [6]. Generally, two factors govern the occurrence and distribution of clay minerals in coastal plain areas: climate and topography. Climate determines the nature of the clay mineral suite by controlling the intensity of weathering [7 - 9]. Understand weathering as a process requires a sound knowledge of the nature and distribution of clay minerals as one of its principal products [10]. The nature of clay minerals in soils is easily affected by soil forming processes [11]. Considering the weathering rates as a function of climate, [12] found that the differences in the clay mineralogy linked well with the weathering intensity [13]. Clay mineral composition basically indicates the intensity of weathering, especially the degree of hydrolysis at source region which can be used as paleoclimatic indicator [14].

Topography influences directly the weathering intensity by controlling the dynamic of drainage, which in turn determines the nature of the weathering products. Clay mineralogy contrasts commonly match the soil drainage contrasts, with minerals indicative of greater leaching associated with the upper slopes positions [15]. The drainage condition caused by topography is a critical factor in the transformation and redistribution of clay minerals [16]. Since drainage influences the moisture regime, seepage, redox potential, and ionic environments, transformation of clay minerals and metal oxides would also be affected by weathering. [17 - 19] illustrate the importance of drainage, where Smectite (S) predominates in poorly drained footslope sections of toposequences, Kaolinite (K) in well-drained sections, and K-S in between in soils of moderate drainage [20]. Despite the considerable body of literature on clay mineralogy, there is still debate regarding the origin of clay minerals in coastal plain areas. Early studies concluded that clay minerals in these interface areas are strongly influenced by diagenetic processes arising from the fact that detrital clay particles are transported from a fresh-water environment to a saline environment [21]. Later work, however, failed to confirm the chemical and mineralogical changes proposed and a consensus has arisen that terrigenous inputs from various sources offer a far more convincing explanation for the majority of clay minerals found in estuarine and coastal sediments [22]. [21] could only cite a very few cases, which were limited to intertropical areas where there was strong evaporation, as in mangrove swamps, where the evidence supported an authigenic origin of clay minerals in estuarine and coastal sediments [22]. Relatively few studies involving coastal soils of Senegal have considered their mineralogical constitution. Our study investigates the origin and distribution of clay minerals in the coastal area of the Saloum river Basin, west central Senegal, in order to demonstrate their impact on local pedogenesis. The clay mineral composition of a soil marks the mineralogical transformations due to soil-forming processes [23]. They are the “genetic signals” of pedogenic events [24]. Clay minerals have been widely used to study paleoclimatic and regional paleoenvironmental reconstructions. Variations of clay minerals in the sediments often reflect climatic changes particularly in tropical environments with efficient chemical weathering [25]. The mineralogical assemblages are also used to identify the mineral sources and to interpret the mineral distribution [26].

II - MATERIAL AND METHODS

II-1. Field Work

II-1-1. Profile Description and Soil Sampling

The sequence of six soil profiles: floodplain (P1-P2), low terrace (P3-P4), middle terrace (P5-P6); was described in the field, and 29 soil samples were collected for laboratory analyses. The sampling transect (1.5 km length) was placed in such a way that influences of the landscape position could be reflected in soil properties. The Munsell soil colours were determined on moist samples. The reaction of carbonate to 10 % hydrochloric acid (HCl) was determined in all samples.

II-1-2. Field Measurements

Topography was determined using a Theodolite. Soils were described after [27]. Electrical conductivity (EC) and pH were estimated with field EC and pH-meters (WTW, 8120 - Weilheim, Germany) before a repetition in laboratory under standard conditions. Groundwater level (GWL) was estimated throughout soil profiles with a measuring tape, twice a week, during the dry season.

II-2. Laboratory Work

II-2-1. Soil Analysis

Bulk soil samples were air-dried at room temperature and passed through a 2 mm mesh sieve to obtain the fine earth fraction. Particle-size analysis was performed after removal of carbonates and organic matter (OM) by treatment with HCl (pH 4.5) and H2O2 (10 %) respectively, and of excessive salts by repeated addition of deionised water, centrifugation and decantation until the electrical conductivity (EC) dropped below 40 µS cm-1. After subsequent addition of ammonia (NH3) for water dispersion, overnight shaking and ultrasonic treatment, the sand fractions (63-2.000 µm) were obtained by wet sieving, while the silt (2-63 µm) and clay (<2µm) fractions were separated by pipette analysis after Köhn [28]. Bulk density was measured for all horizons using a steel cylinder of 100 cm3. Soil samples were then oven-dried at 105°C and weighted to determine the soil bulk density in g cm-3. Soil pH was measured in water at a soil: solution ratio of 1:2.5. The electrical conductivity was determined using a 1:5 soil: water extract [28].

II-2-2. Mineral Analyses

X-ray diffractometry (XRD) of fine earth was determined as powder. Clay mineralogy was determined by X-ray diffraction (XRD) of oriented clay specimens using a Siemens D-500 instrument with Cu Kα radiation. Different treatments of the clay samples included K and Mg saturation, heating to 110°C, 220°C, 400°C and 600°C of the K- and glycerol salvation of the Mg-saturated samples. A Scanning Electron Microscope (SEM) LEO 420, equipped with a field emission cathode and coupled to an Energy Dispersive X-ray (EDX), INCA 400 system, was used to confirm the mineral composition. The amounts of the different clay minerals were estimated on a semi-quantitative basis using the computer package DIFFRAC AT V3.3 Siemens 1993. Soil profiles were divided into three parts: topsoil, central horizons, and subsoil; for this purpose. Clay minerals are individually presented to assess their abundance in soil profiles. The method assumes that the available minerals in the sample sum to 100 % and the individual mineral is a fraction of the total. Illite/Smectite mixed layers (I-S) was excluded from this semi-quantification; due to trace amounts it shows in the entire toposequence. This fraction was therefore subtracted from the total sample (100 %). Percentages of clay minerals are then recalculated from the total of sample without the I-S content.

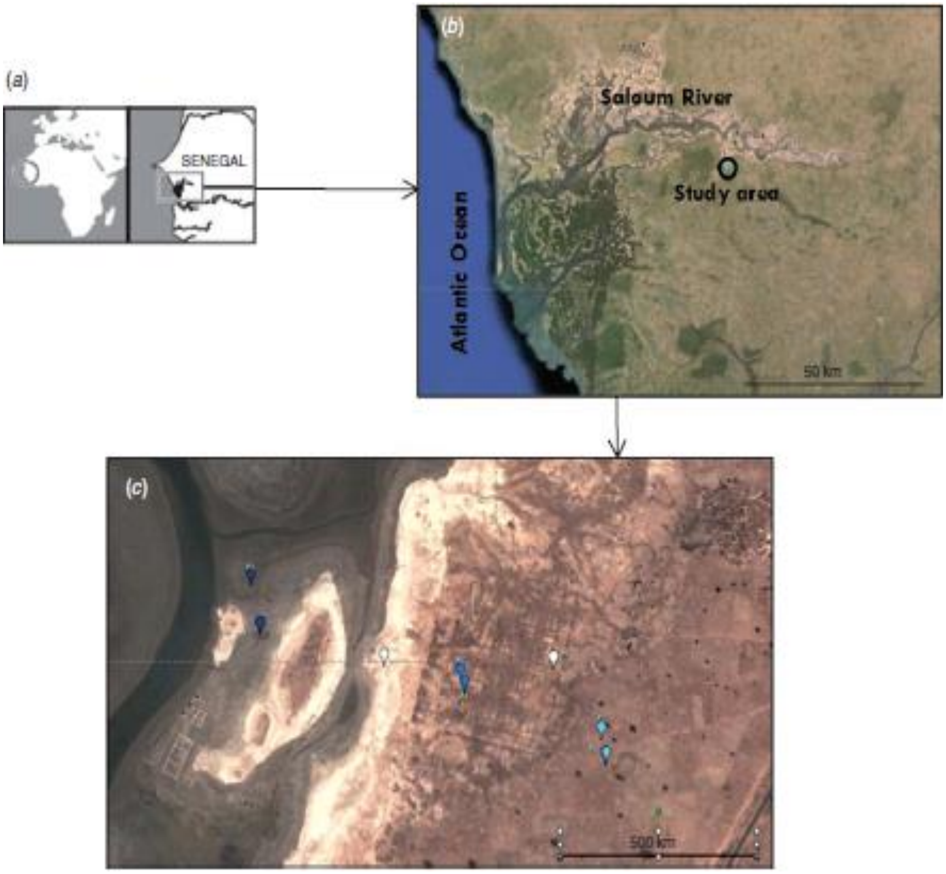


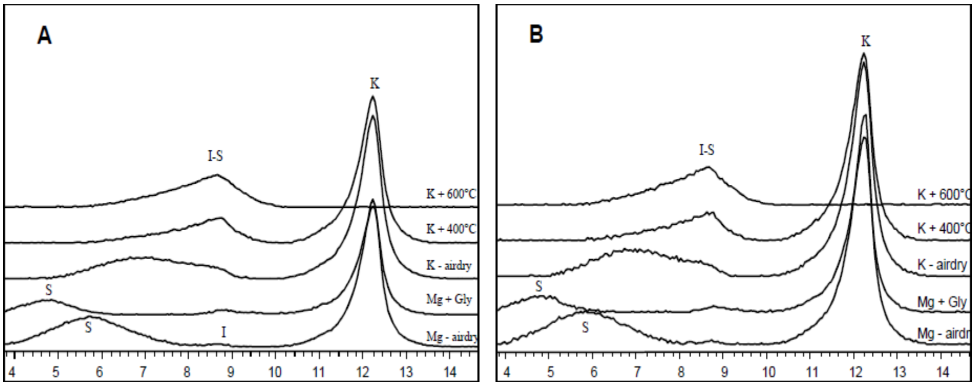
Figure 1 : *(a) The Saloum River basin in Senegal, with (b) indication of the study area and (c) the investigated transect and profiles (adapted from Google Earth, 2019)*

III - RESULTS

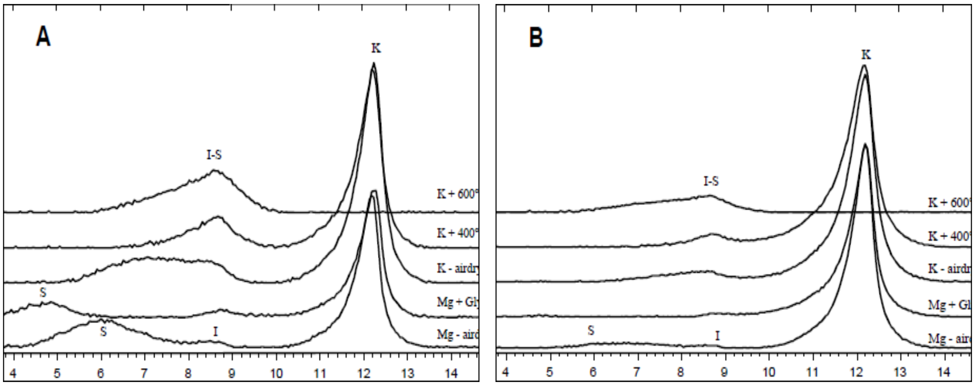
Clay minerals were investigated at each landscape position for a comparative purpose. They were then analysed with regard to their cristallinity (qualitative analysis) and their abundance (semi-quantitative estimation). Clay minerals are broadly dominated by Kaolinite and Smectite, while Illite and interstratified Illite-Smectite (I-S) are generally low-contained in soils.

III-1. Qualitative analysis

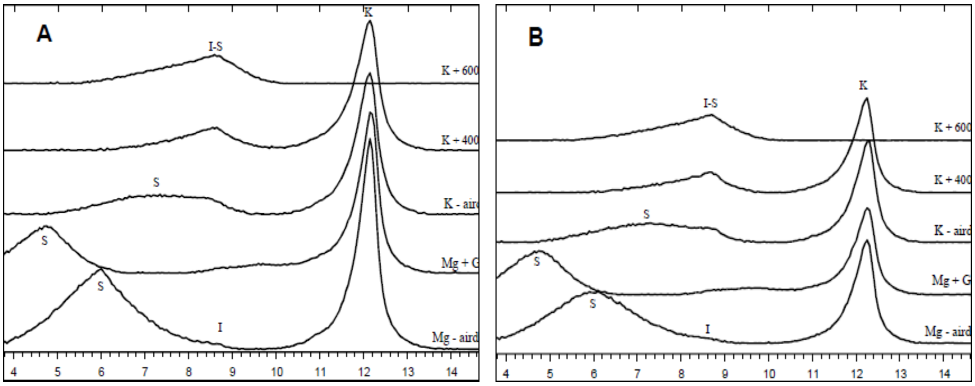
Kaolinite was identified from its intense 0.72 nm reflection, which disappeared when K-saturated clays were heated to 600°C. The Mg-saturated samples after glycerol solvation showed a *d*-spacing expansion (shifting from 1.4 to 1.8 nm) in the air-dried state, which indicates the presence of Smectite. The XRD patterns for the Mg- and K-saturated clays showed a weak 1.0 nm peak, indicating the presence of Illite. The presence of I-S was indicated by the wide and shallow convexity between 1.0 and 1.4 nm in the K-saturated air-dried sample. Floodplain soils show strong peaks at 0.72 nm, indicating well-crystallized Kaolinite. This clay mineral decreases slightly in cristallinity in the central horizons of soil profiles ***(Figure 2)***. Smectites peaks change slightly with depth throughout floodplain soils; they appear sharper in the topsoil but broader in the subsoil. Illite decreases in cristallinity with depth. It shows hints in the subsoil, contrasting with the small but distinct peaks yielded in the topsoil. I-S shows broad peak shoulders in the K-saturated air-dried samples, indicating ongoing weathering processes on this lowest landscape position. Low terrace profiles show well-crystallized Kaolinite at all depths ***(Figure 2)***. Smectite shows small peaks in the topsoil, which become broader in the subsoil, but decline appreciably in the central part of these profiles. Illite and I-S show less cristallinity with smaller and narrower peaks on this intermediate landscape position. Middle terrace profiles contain less Kaolinite. Kaolinite cristallinity decreases here appreciably with depth ***(Figure 2)***. The particularity of these soils remains the significant amounts of Smectite they contain, the highest in the entire toposequence. This clay mineral shows wide and sharp peak on the topsoil. Peak intensity decreases significantly downwards, suggesting decreasing cristallinity with depth. Illite is low-contained, whereas I-S is totally absent in these soils ***(Figure 2)***.



Floodplain soils (P1): topsoil (A) and subsoil (B)



Low terrace soils (P4): topsoil (A) and subsoil (B)



Middle terrace soils (P6): topsoil (A) and subsoil (B).

Figure 2 : *Clay mineral distribution in studied soils : K = kaolinite; S = Smectite; I = Illite; I-S = Illite-smectite mixed layers*

III-2. Semi-quantitative estimation of clay minerals

Clay minerals are individually presented to assess their abundance in soil profiles. The method used assumes that the available minerals in the sample sum to 100 % and the individual mineral is a fraction of the total. I-S was excluded from this semi-quantification; due to trace amounts (< 1 %) it shows in the entire toposequence. This fraction was therefore subtracted from the total sample (100 %). Percentages of clay minerals were then recalculated from the total of sample without the I-S content. In general, Kaolinite is the dominant clay mineral in the entire toposequence with strong peaks and nearly constant amounts with depth throughout all profiles. Differences are however observed regarding its spatial distribution. The highest amounts are obtained in the low terrace profiles with 84 % (in average) of the clay mineral assemblage, versus 72 % in the floodplain, and 62 % in the middle terrace ***(Table 1)***. It declines slightly in abundance in the central part of floodplain profiles, but increases again in the subsoil. The reverse trend is noted in the low terrace profiles: Kaolinite is more abundant in the central horizons compared to the top- and subsoil ***(Table 1)***. Kaolinite shows different distribution trend in the middle terrace profiles: it decreases globally in P5 but increases steadily in P6 ***(Table 1)***. Smectite has an opposite distribution trend compared to Kaolinite: the highest amounts are recorded in the central horizons for the floodplain and middle terrace profiles and in the top- and subsoil for the low terrace profiles ***(Table 1)***. Smectite is generally more contained in the middle terrace profiles with an average of 37 % of the clay mineral assemblage. It represents the second most abundant clay mineral in the floodplain profiles (26 % in average), while the lowest amounts (around 15 %) were obtained in the low terrace profiles. Noteworthy remains the lowest Smectite amount (6 %) obtained in the central horizons of low terrace profiles, corresponding to the fluctuation zone of the groundwater table at this intermediate landscape position. Illite amounts increase seaward with the highest values yielded in the floodplain profiles (2 % in average). It was however obtained similar amounts (1 % in average) in the low terrace and the middle terrace profiles, except for the topsoil of the former (2 % for P3 and P4) and the subsoil of the latter (2 % for P5 and P6) landscape positions. Values of Illite decrease generally with depth in the floodplain and the low terrace profiles, but increase with depth in the middle terrace profiles ***(Table 1)***.

Table 1 : *Semi-quantitative estimation of the clay mineral abundance in the topsoil, central horizons, and subsoil of the floodplain, low terrace, and middle terrace*

Horizon	**Depth (cm)**	**Kaolinite (%)**	**Smectite (%)**	**Illite (%)**	**Total (%)**
Floodplain – P1					
Topsoil	0-4	75	23	2	100
Central Horizons	4-23	67	32	1	100
Subsoil	23-60	71	28	1	100
Floodplain – P2					
Topsoil	0-8	83	14	3	100
Central Horizons	8-30	64	35	1	100
Subsoil	30-60	70	29	1	100
Low terrace – P3					
Topsoil	0-16	81	17	2	100
Central Horizons	16-62	94	5	1	100

Subsoil	62-100	87	12	1	100
Low terrace – P4					
Topsoil	0-11	85	13	2	100
Central Horizons	11-51	91	8	1	100
Subsoil	51-100	67	32	1	100
Middle terrace – P5					
Topsoil	0-60	82	17	1	100
Central Horizons	60-108	72	26	2	100
Subsoil	108-160	75	23	2	100
Middle terrace – P6					
Topsoil	0-62	41	58	1	100
Central Horizons	62-107	47	52	1	100
Subsoil	107-160	58	40	2	100

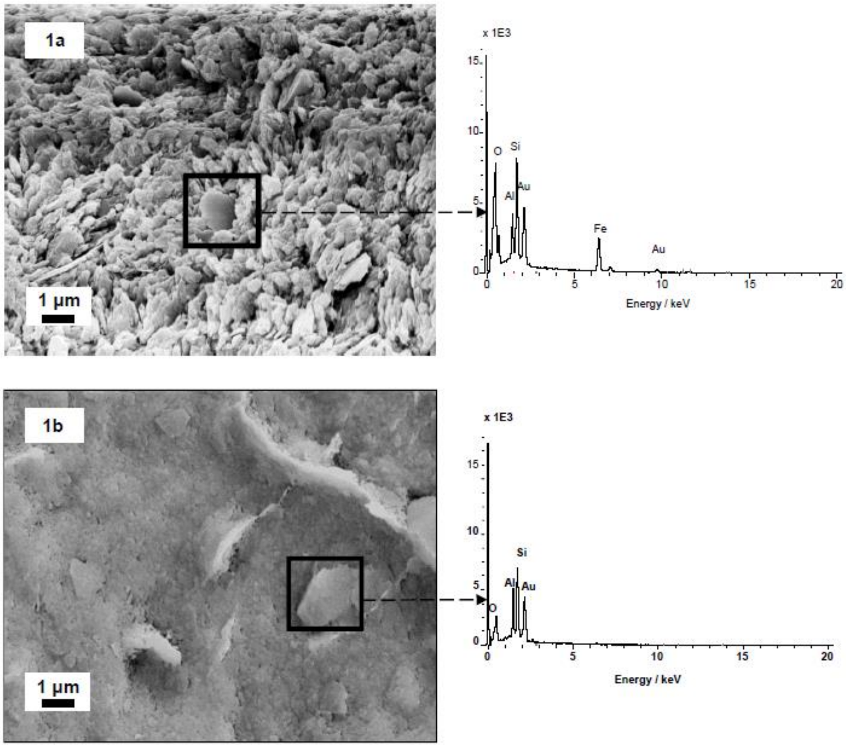


Plate 1 : *SEM and EDX showing kaolinite platelets in the floodplain (1a - P1: Gleyic Hyposalic Solonchak (Sulphatic); Bjv horizon: 4-23 cm) and low terrace (1b – P3: Haplic Gleysol (Thionic); Bl1: 16-38 cm)*

IV - DISCUSSION

Kaolinite is highly contained in all soil profiles and at all landscape positions in the present study. This widespread occurrence of Kaolinite in various topographic and lithological situations suggests regional accession of aeolian dusts. A substantial input of detrital Kaolinite from the continental uplands seems a convincing argument. This view is substantiated by the highest abundance of Kaolinite in low terrace soils. Kaolinite at this intermediate landscape position most probably has two origins, which can be ranged, according to their contribution to the global Kaolinite fraction, in the following descending order: detrital > authigenic. Detrital (or terrigenous or allochtonous) Kaolinite corresponds to the Kaolinite carried with eolian dusts material from the continental uplands. Heterogeneity of soil parent material was more evidenced throughout low terrace profiles. Also the SEM and EDX analysis depicted amorphous Kaolinite platelets on the low terrace position (Plate 1b) compared to the well-structured Kaolinite crystals obtained on the floodplain (Plate 1a). This suggests detrital Kaolinite on the previous landscape position. Authigenic Kaolinite is suggested with respect to the acid pedoenvironmental conditions ($3 \leq pH \leq 5$) prevailing at this intermediate landscape position. Such conditions are demonstrated to favour the transformation of Smectite into Kaolinite.

The formation of clay minerals is dependent on physicochemical conditions of the immediate weathering environment, nature of the starting materials and other related external environmental factors [2], thus resulting into various types of clay materials [29]. The stability diagrams available in the literature showed that Kaolinites are stable under low values of pH-pK and pSi(OH)4 at ambient pressure and temperature, typical conditions of acid, well-drained, and leached soils [30]. With sufficient time in the intense leaching regime associated with most tropical soils, the mineral assemblage evolves to one dominated by kaolinite and sesquioxides, and soil chemistry becomes characterized by a large amount of available Al, a small base cation content, low pH [31]. Formation of disordered Kaolinite seems a probable transitional phase for this diagenetic process. Disordered Kaolinite is believed to form as a metastable precursor to Kaolinite [32] that is kinetically favoured by rapid crystallization following parent rock dissolution. Either way, disordered Kaolinite formation is favoured by the Al- and Si-rich, base-poor soil water that characterizes most tropical soils [20]. Floodplain soils contain less Kaolinite because the low topographic position and the distance from the source reduce significantly the contribution of eolian dust inputs. Also the neutral soil pH induced by the high base saturation limits the authigenic formation of Kaolinite from alteration of 2:1 silicates, mainly Smectite or Illite.

As soils described by [30] in the Pantanal Wetland of Brazil, floodplain soils are alkaline due to their poor drainage, and as saline soils, they have high base saturations. Such conditions are opposite for the ideal formation of Kaolinite. Diagenetic formation of Kaolinite is, for this reason, marginal at this lowest landscape position. Kaolinite generally increases upwards in the floodplain profiles. The same trend was also observed by [33]. Although weathering of 2:1 silicates cannot be precluded, such a distribution seems more likely to be due to selective translocation of Smectite-rich, finer-clay particles, or the formation of Smectite in the lower parts of the profile, or both [34]. Kaolinite in the middle terrace appears essentially of detrital origin. It originates most likely from the nearby uplands (high terrace and plateau). Authigenic Kaolinite may be promoted here by the strong leaching caused by the high topographic position and the permeability of soil material. Smectite is commonly altered to Kaolinite, where weathering, especially leaching, is intense [35, 36]. Low terrace profiles contained the highest amounts of Kaolinite because the pedoenvironmental conditions necessary for Kaolinite occurrence in soils are better fulfilled. Evidence for airborne addition of Kaolinite is also suggested with respect to the relative young parent material (Holocene sediments) which appears not enough to produce appreciable amount of well-crystallized Kaolinite yielded in almost all samples. It generally takes much ≥ 10 000 years to produce a soil containing pedogenic Kaolinite as a major constituent [37].

This supported the presence of detrital Kaolinite inputs from highly weathered upland soils. [38] explained the occurrence of advanced weathering products such as Kaolinite and crystalline Fe and Al in recent parent materials of the River Niger floodplain, eastern Nigeria, to addition of intensive weathered material from the upland. Lack of mineral stability studies complicate however considerably these interpretations. [39] noted that two factors make the interpretation of mineral addition in soils more difficult: metastability and formation of unstable intermediate phases. Formation of pedogenic Kaolinite and Smectite has been linked to topographic position by some authors [15, 40]. Generally, upslope clay-mineral suites will be more depleted in silica relative to downslope clay-mineral suites, which will be characterized by silica accumulation. We ascribe the presence of Smectite in the floodplain soils to high water saturation linked to permanent tidal flooding and a shallow water table. Also the fine texture reduces the soil permeability and impedes substantial leaching. This favours the accumulation of silica and basic cations, suitable conditions for the formation of authigenic Smectite. Smectite in these topographic low soils may also derive from the alteration of Illite. Evidence of Illite alteration into Smectite was reported in many coastal plain soils. It requires however several rearrangements in the mineral structure, principally a decrease of the layer charges (K-depletion). Without this decrease, Illites do not have the low charges characteristics necessary for them to exhibit the properties of Smectites [41]. Illites in floodplain profiles are more abundant in the topsoil, where Smectite appeared less abundant (Table I). This suggests proceeding weathering characterized by progressive illitisation of Smectite. There is a distinct possibility that Smectite is converted to Illite by potassium addition to the interlayers of the structure in soils of arid regions, especially in surface horizons [34]. Interstratified Illite-Smectite (I-S) seems a probable transitional phase for such process; it was essentially detected in floodplain profiles. The upward decrease of Smectite may also be linked to instability of Smectite in the topsoil of floodplain profiles compared to the subsoil. Smectite often increases in amount and/or cristallinity with depth in soils developed from unconsolidated materials in semiarid and arid regions [42, 43]. Such trends suggest (1) synthesis in the lower horizons, (2) instability in the upper horizons, or (3) preferential translocation of the Smectite [34]. There is also considerable evidence that Illite may be pedogenically formed by the conversion of an expanding clay (e.g. Smectite) to a “1-nm” mineral in arid and semiarid region soils [44]. An increase of Illite upwards in profiles is often invoked as evidence of such conversion. The highest amounts of Smectite were yielded in middle terrace profiles. The presence of Smectite in these well-aerated and topographic high soils appears complex.

Although the evidence indicates that detrital inputs exert a major influence on the clay minerals in the sediments examined here, it seems unlikely that the occurrence of the Smectite mineral can be explained in this way, for two reasons. Firstly, the occurrence of Smectite in tropical soil catena appears to be constrained to topographic low positions [15, 40]. In contrast to soils containing mostly inherited Smectite, other soils have predominantly pedogenic Smectite. The Smectite apparently weathers to Kaolinite/halloysite in the uplands but is preserved in the topographic lows [34]. [45] even reported more Smectite in poorly drained than in associated, better-drained soils in Scotland. Secondly, Smectite is not related as a major component of eolian dust inputs in the coastal region of West Africa, compared to Kaolinite, because the above-mentioned conditions preceding its formation are not met in the identified dust source areas. The possibility for original marine Smectites to be significant components of eolian dusts is however not to be precluded. [46] considered the Lake Chad as probable source of Smectite found in the eolian dust additions of some soils of Niger. This argument is corroborated by [47] who found that the formation of Smectite from soluble sediments remains an ongoing process in the Lake Chad. Although the Bodele depression was considered as the major source of Harmattan dust in the eastern part of West Africa, evaluation of meteorological data indicates other minor sources in the Lake Chad region and at the footslopes of the Aïr Mountains [46]. Smectite occurrence in the middle terrace may also be partly attributed to the presence of a restrictive layer for water infiltration in the soil profiles. The intermediate landscape position of low terrace profiles affords the contribution of both soil physical parameters (water table and restrictive layer for water infiltration) in the formation of Smectite. However the acid conditions prevailing in this site limit significantly the formation of authigenic Smectite. The lowest amounts of Smectite ($\leq 8\%$) were obtained in these profiles, precisely in the central horizons corresponding with the fluctuation zone of the groundwater table (oxic/anoxic boundary). The lowest pH values were obtained at this depth in a former study [48]. We consider, therefore, that the high soil acidity limits the formation of authigenic Smectite and promotes its alteration to Kaolinite in the low terrace. This supports the highest amounts of Kaolinite yielded in these profiles. Smectite is unstable under acid soil conditions because of removal of bases and/or silica, and usually a decreased pH [34]. The factors that strongly influence the origin and formation of Smectites in soils, as reviewed by [41], include low-lying topography, poor drainage and base-rich parent material, leading to favourable chemical conditions characterized by high pH, high silica activity and an abundance of basic cations [2].

These conditions are met in many soils under temperate or cold climates or even in tropical climates where leaching is limited for various reasons, including low precipitation, a horizon in the soil profile that impedes the passage of water or a naturally high water table [34]. Smectite can be pedogenically formed under such conditions or be preserved, if it is inherited. It does not form (or persist) where leaching is intense because of losses of bases and/or silica [34]. Illite in studied soils may have many origins. It can directly derive from the weathering of mica-rich marine sediments. It can likewise be the result of airborne dust inputs from the continental uplands. There is also growing evidence that Illite may be pedogenically formed by the conversion of an expanding clay (e.g. Smectites) to a 1-nm mineral in arid and semiarid region soils [44]. [49] listed 3 necessary steps for the transformation of Mica (Illite) into Smectites to occur in soil: (1) depotassication, dealumination of the tetrahedral sheet followed by silication of the tetrahedral sheet. The reverse process - Smectite precursor of Illite - may also be considered in estuarine environments. [50] reported that cyclic changes in the redox potential at the soil surface of a salt marsh led to the formation of Smectite minerals from the transformation of Illite and Chlorite.

V - CONCLUSION

Different hypotheses have been addressed to explain the origin of clay minerals in estuarine and coastal plain sediments. Our study demonstrated that Clay minerals in the coastal area of West Central Senegal are partly authigenic (formed by in situ precipitation from a concentrated solution), partly detrital (from eolian dust inputs). The contribution of each category is site-dependent, i.e. determined by prevailing pedoenvironmental conditions and the landscape position. Authigenic minerals are influenced by the acid and saline conditions. This explains the highest amounts of kaolinite and lowest amounts of smectite in the more acid soils (low terrace), while illite and illite/smectite are more present in saline and less acid soils (floodplain). The distribution of detrital clay minerals is mainly governed by landscape position, which influences the importance of eolian inputs by determining the distance to the dust sources. Ultimately more detrital than pedogenic clay minerals were identified. The contribution of eolian dust inputs to clay mineral distribution was largely demonstrated. They provide kaolinite-rich allochtonous material from regional sources or farther. This supports the high abundance and widespread occurrence of detrital kaolinite in the entire toposequence.

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